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Indium distribution in pseudomorphic InGaAs/(Al)GaAs quantum wells grown by MOCVD

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Abstract. Indium atom distribution in InGaAs/(Al)GaAs quantum wells (QWs) grown by metal organic chemical vapor deposition (MOCVD) was systematically studied. High resolution grazing sputter angle Auger electron spectroscopy was used as a method of indium depth profile investigation. Broadening and shift to the surface of indium concentration profile in single QW, the increase of indium content in upper quantum well for close spaced QWs were found. It was observed that the use of AlGaAs barriers between QWs reduces indium surface segregation.

Introduction

In last decades InGaAs/AlGaAs quantum well heterostructures are widely used in optoelectronic and microwave applications. Fabrication of high quality devices demands flat and abrupt QW interfaces. Surface segregation of indium atoms during growth process causes indium enrichment of upper layer and broadened QW interfaces. These phenomena have been observed using second ion mass spectroscopy [1], Auger electron spectroscopy (AES) [2], reflection mass spectrometry [3], reflection high-energy electron diffraction [2, 4], ultraviolet photoemission spectroscopy [2, 5], transmission electron microscopy [6], X-ray diffraction [6, 7], photoluminescence [1], electrolyte electroreflectance [8]. Special growth procedures to improve interface abruptness are required. The main part of indium surface segregation investigation were carried out on molecular beam epitaxy grown InGaAs QW heterostructures. At the same time for device manufacturing the metal organic chemical vapour deposition large-scale production is necessary. In this work we study indium distribution in InGaAs/(Al)GaAs QWs grown by MOCVD. High depth resolution AES was chosen as an indium profile investigation method.

1. Experiments

The InGaAs/(Al)GaAs QW heterostructures were grown on n^+-GaAs substrates by low pressure MOCVD at Sigm Plus Co. The patented design homemade rectangular quartz tube horizontal reactor "SIGMOC-130" with gas flow rotation of susceptor was used. TEGa, TMAl and TMIn were used as group-III sources and arsine as a group-V source. Growth was performed at temperature 720 °C and pressure 60 torr on (001) with 0.5° misorientation toward the [110] GaAs substrates.

Five types of InGaAs/(Al)GaAs QW heterostructures were investigated. Sample A consisted of single InGaAs quantum well sandwiched between GaAs spacer layers and AlGaAs barrier layers (inset to Fig. 1(a)). Sample B consisted of two InGaAs quantum wells separated by GaAs barrier. QWs were sandwiched between GaAs spacer layers and

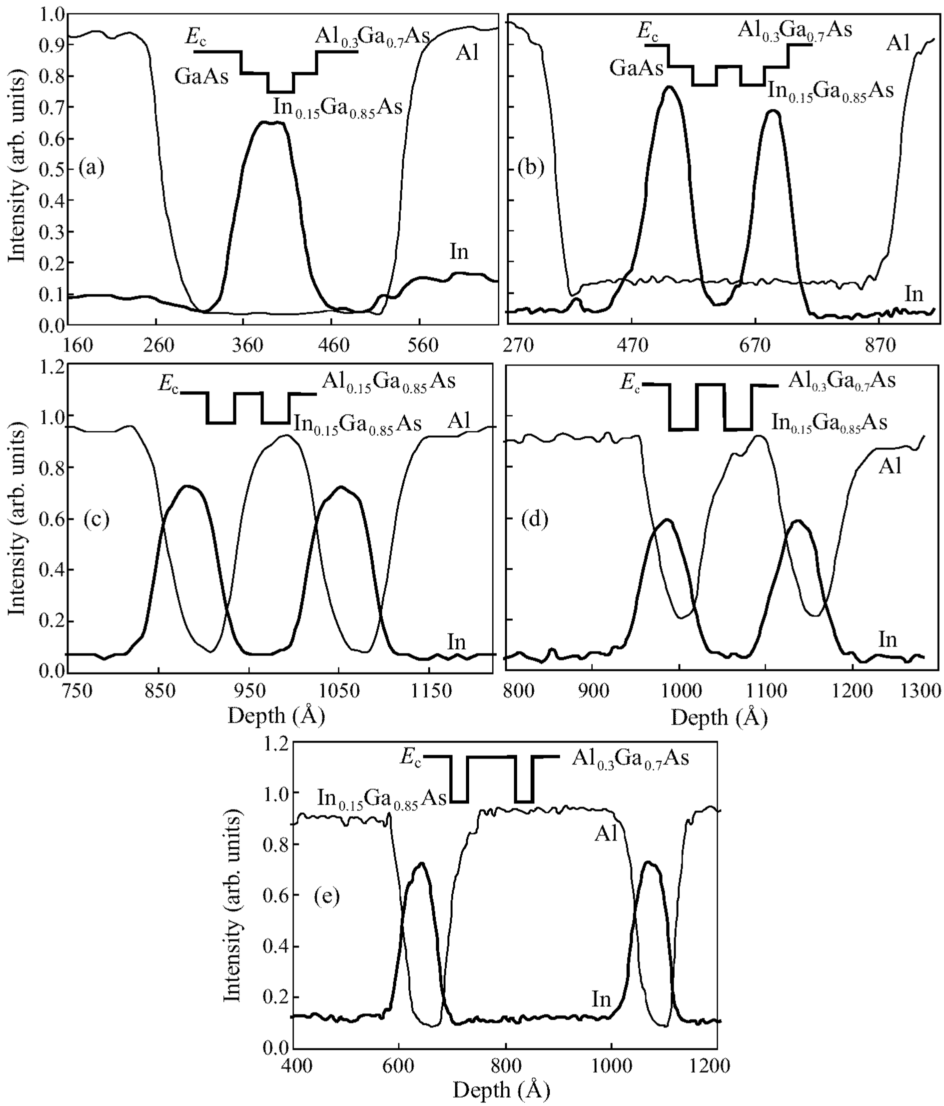

Fig. 1. AES depth profiles of: (a) sample A; (b) sample B; (c) sample C; (d) sample D; (e) sample E. The insets show conduction band edge of samples.

AlGaAs barrier layers (inset to Fig. 1(b)). Sample C was identical to sample B but GaAs layers were replaced by $Al_{0.15}Ga_{0.85}As$ layers (inset to Fig. 1(c)). Sample D was identical to sample C but $Al_{0.15}Ga_{0.85}As$ layers were replaced by $Al_{0.30}Ga_{0.70}As$ layers (inset to Fig. 1(d)). Sample E consisted of several periods of InGaAs/$Al_{0.30}Ga_{0.70}As$ superlattice (inset to Fig. 1(e)).

The InGaAs/(Al)GaAs QW heterostructures were investigated by AES. The AES depth profiling was performed at Scanning Auger Spectrometer PHI-560. In order to improve the depth resolution low energy Ar^+ ions (1 keV) and a grazing sputter angle profiling (80° with respect to surface normal) was used.

2. Results and discussion

AES depth profile of sample A demonstrates broadening of upper QW interface via indium surface segregation effect (Fig. 1(a)). During epitaxial growth indium atoms tend to move to upper layer [1, 2]. Therefore the peak of indium distribution is shifted toward growing surface in relation to GaAs/AlGaAs interfaces. Indium segregation length (λ) determined as $1/e$ decay length of In from AES profile is 42 Å. The segregation probability (R) of In atoms from topmost layer determined as $R = \exp(-d/\lambda)$ [1] is 0.93. Here d is half the lattice constant of GaAs. Surface segregation effect leads to narrowing of upper GaAs spacer layer. The thickness of upper spacer has a great influence on the threshold current of laser diodes based on InGaAs/AlGaAs QW heterostructures. Therefore the growth process must be corrected to obtain optimal thickness of spacers [9].

If indium segregation probability is rather high and distance between QWs is small the indium atoms from deeper QW can reach upper QW and increase indium content in it. This situation is illustrated by sample B AES profile (Fig. 1(b)). Distance between QWs is 100 Å and indium segregation length is 45 Å, $R = 0.94$. In this case two different phenomena occur. As in case of sample A the indium peak shift to growth direction is observed. Moreover upper QW is enriched with indium atoms segregated from deeper QW during growth process. The ratio of upper QW indium peak intensity to deeper QW indium peak intensity (I_{DQW}) is 1.15. This phenomenon may result in appearing of particularities in emission spectrum of laser diodes (especially for single mode devices) [10].

It was observed that the replacement of GaAs barriers and spacers by AlGaAs barriers (sample C and D) decreases indium segregation in QWs. Figure 1(c) shows that indium peak shift for is less than that one for sample B. AlGaAs barriers decrease indium carry over into upper layer. Hence indium segregation length and probability ($\lambda = 33$ Å, $R = 0.92$) decrease and both QWs have approximately the same indium content ($I_{DQW} = 1.03$). The substitution of $Al_{0.15}Ga_{0.85}As$ (sample C) on $Al_{0.30}Ga_{0.70}As$ (sample D) lead to further decrease of both indium peak shift ($\lambda = 29$ Å, $R = 0.91$) and difference of indium content in QWs ($I_{DQW} = 1.01$) (Fig. 1(d)).

However if distance between QWs is considerable as in case of sample E ($Al_{0.30}Ga_{0.70}As$ barrier thickness 350 Å) QWs have an identical indium content (Fig. 1(e)). The indium peak shift toward upper InGaAs/$Al_{0.30}Ga_{0.70}As$ interface still remains ($\lambda = 32$ Å, $R = 0.91$).

For receiving of identical InGaAs/(Al)GaAs QWs with sharp interfaces by MOCVD it is necessary to use rather thick AlGaAs barriers with high AlAs mole fraction. Developing InGaAs based heterostructures the indium surface segregation effect leading to observed phenomena should be taken into account.

Summary

In summary indium atoms distribution in InGaAs/(Al)GaAs QWs grown by MOCVD were systematically studied using grazing sputter angle AES. The shift of indium concentration profile toward the surface in single QWs and relative shift of composition in close spaced multiple QWs were found.

The influence of barrier materials on indium distribution in QWs was investigated. The increase of AlAs mole fraction in AlGaAs barrier resulted in the decrease of indium surface segregation.

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